NREL National Renewable Energy Laboratory

Encouraging the Development of Biorefineries

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24th Symposium on Biotechnology For Fuels and Chemicals

Gatlinburg, Tennessee, April 28 - May 1, 2002

Biomass Processing

Emphasis has been on fuel-grade ethanol

- By-products limited to power (and heat) generated from process waste

Recovery of production costs by a single major product

- Limits flexibility to recover investment & operating costs

Ethanol will probably continue to form the “back bone” of a biomass refinery

- Large market demand

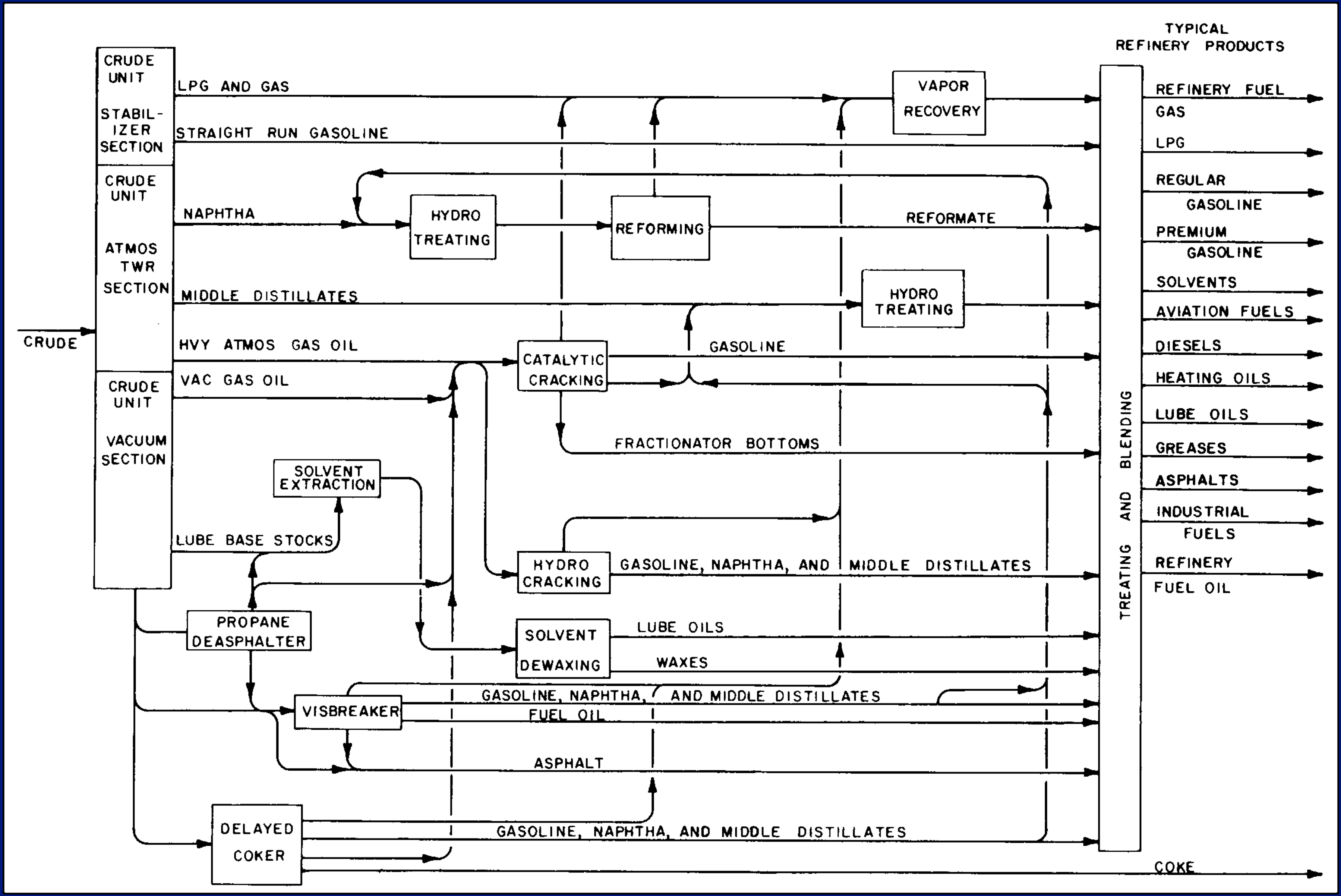
Key Aspects of "Biorefinery"

Multiple products

Increased production of one product decreases production of another

- Production decisions must be based on a variety of considerations
  - » <u>Local</u> economics for all products
  - » Contractual agreements
  - » Plant's operating limits

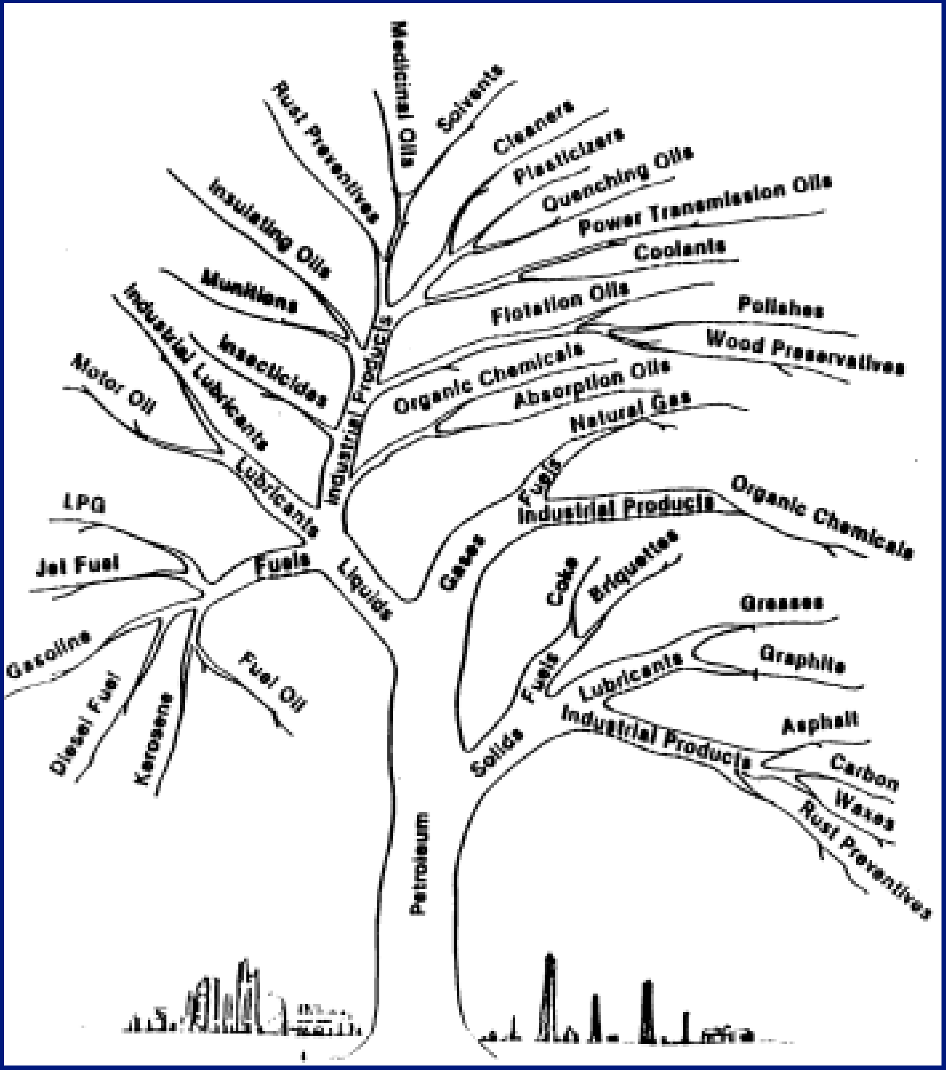
Petroleum Refinery as Analogy



From ***Petroleum Refining — Technology & Economics***, 4th ed., J. H. Gary & G.E. Handwerk, Marcel Dekker, Inc., 2001

Petroleum Refinery as Analogy

- There are specifications for over 2,000 individual refinery products
- Intermediate feed stocks can be routed to various units to produce different blend stocks
  - » Depends upon the local economics & contractual limitations



Lessons Learned from Petroleum Refineries?

Over 100 years to develop current product slates

- First "refinery" 1861
- Distillation $\Rightarrow$ combination of distillation & conversion units

Products & their specifications have come & gone

- Kerosene first product
  - » Tar & naphtha undesirable by-products
  - » Electric lights decreased demand for kerosene
- Internal combustion engines $\Rightarrow$ increased demand for naphtha/gasoline
  - » High performance engines $\Rightarrow$ high quality & tight specifications

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Lessons Learned from Petroleum Refineries?

Conversion processes have come & gone

- Early refineries relied solely on distillation
- Thermal cracking processes
- Catalytic cracking processes
  - Fluidized Bed Catalytic Cracking foundation of modern refining
- Reforming processes

Major upheavals in society have resulted in major upheavals in the ***application*** of technology

- World War II
  - » Fluidized Bed Catalytic Cracking
  - » Reforming
- Clean Air Act
  - » Hydrodesulfurization
  - » Reformulated gasolines

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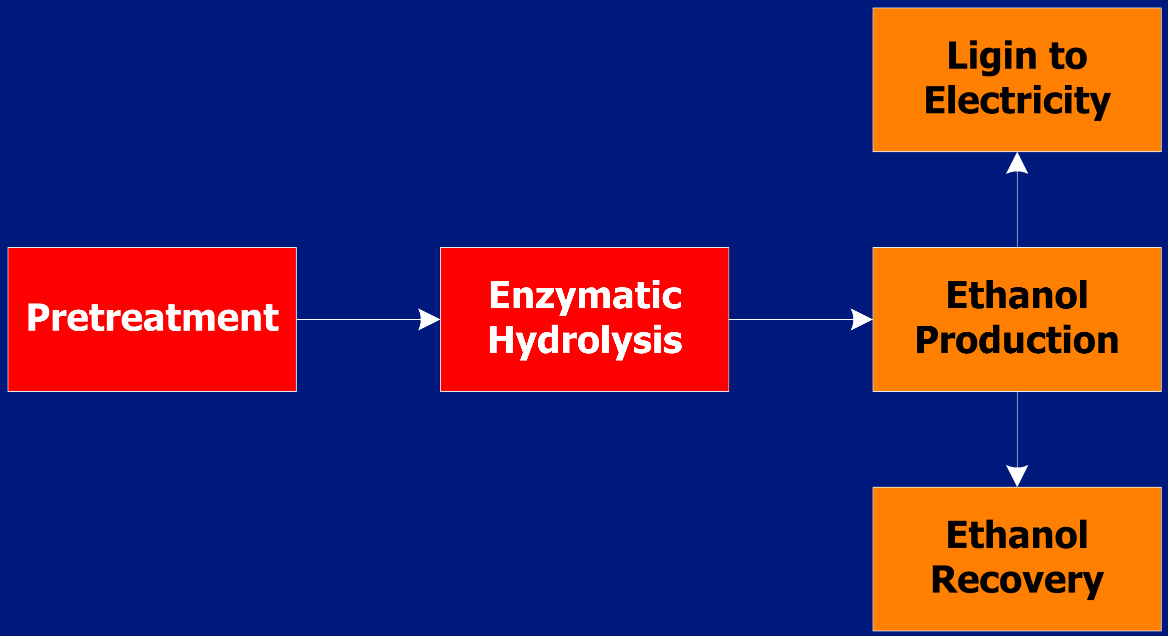
Biomass Processing Philosophy for Fuel Grade Ethanol

- Emphasis is to convert feedstock carbohydrates to ethanol
- Non-carbohydrate wastes burned for power (and heat) to run process
  - » Export excess electricity for credit



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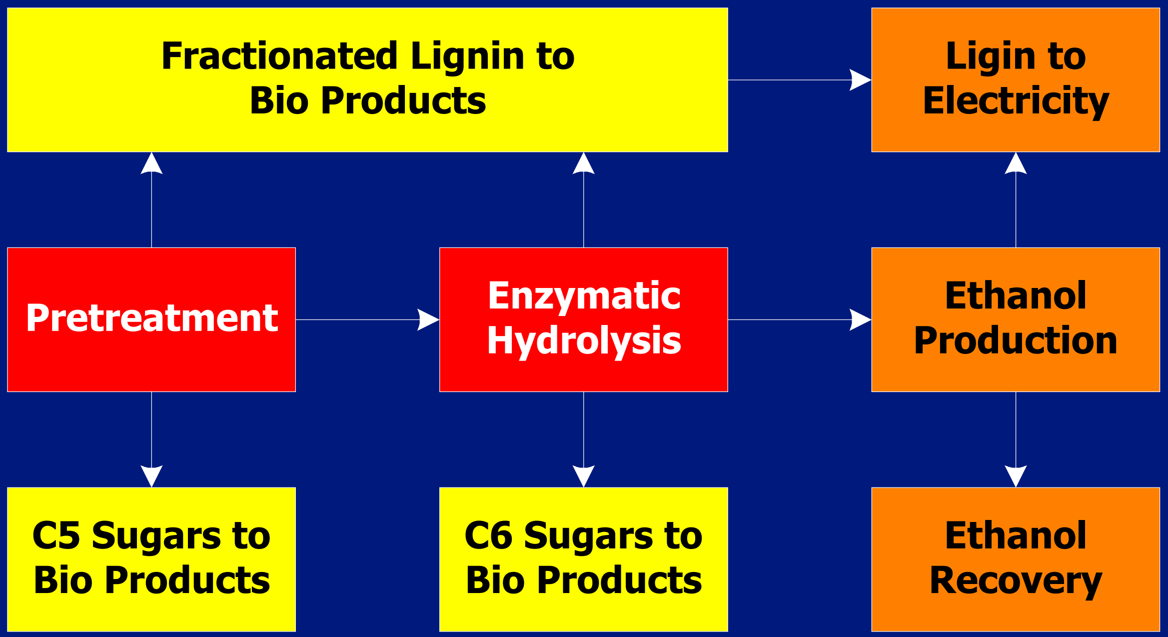
Potential Biorefinery Processing Philosophy

- Flexibility to produce multiple co-products
  - » Co-products decrease ethanol and/or power (and heat) production
  - » Co-products spread recovery of capital & operational costs



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Biorefinery Needs

Commercial

- Co-products & potential markets
  - » Replace current sources for raw materials
  - » New materials

Technology

- Conversion
  - » Biological & Chemical
- Separation
  - » Solids from liquid solutions (slurries)
  - » Components from dilute aqueous solutions

Planning

Broad Categories of Biomass Products

Lipid-based products

- Fatty acids, alcohols, esters derived from fats & seed oils
- Technology available now
- Does not offer largest market potential

Pyrolysis products

- May be cost competitive with currently available technology

New “biomonomers”

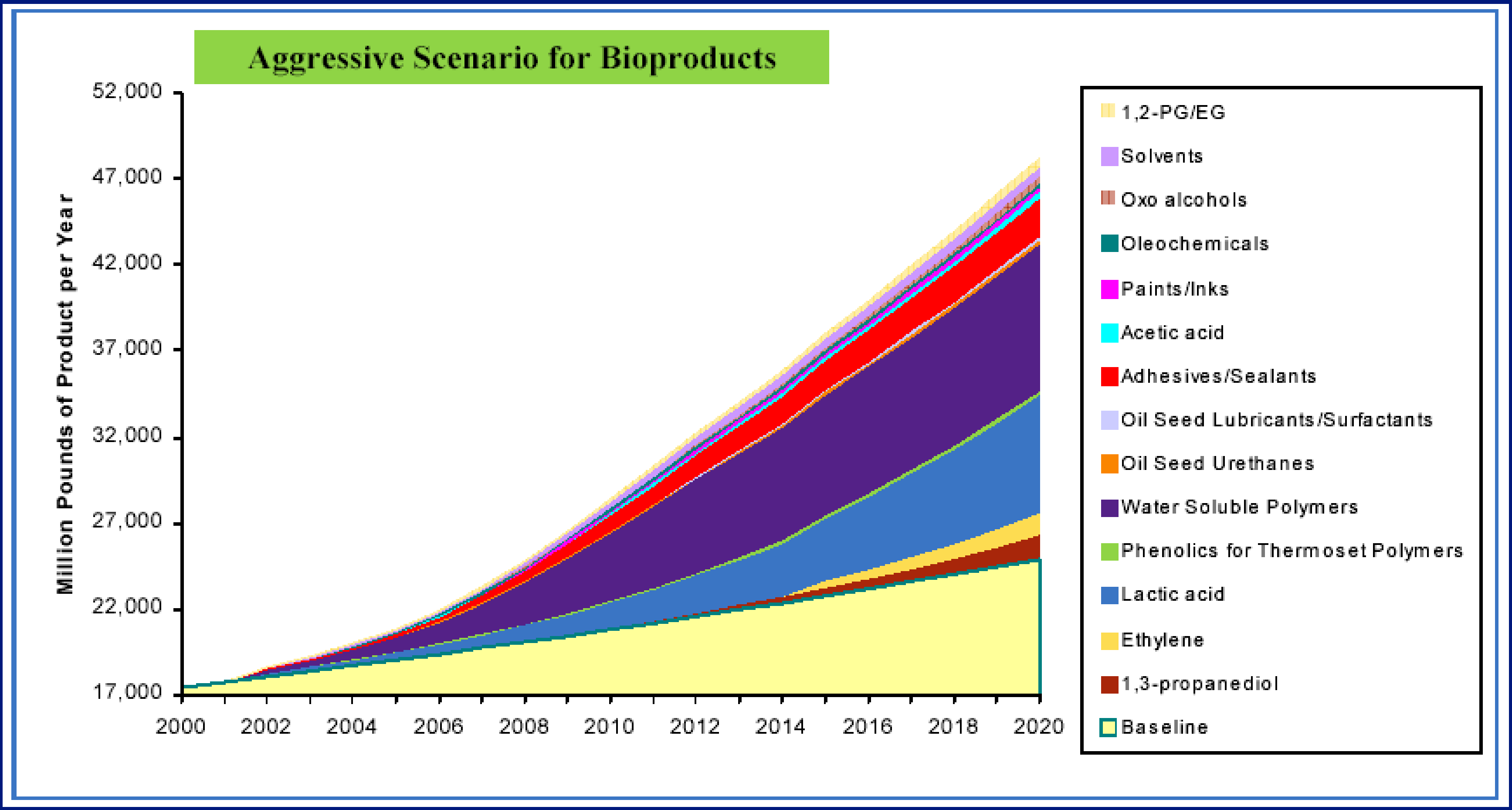
- Produced via fermentation
- Significant industrial interest in development & potential

Syngas-based products

- Competes with natural gas-based alternatives

“Aggressive Growth in the Use of Bio-derived Energy and Products in the United States by 2010,” Final Report, Arthur D. Little, Inc., DOE contract number GS-23F-8003H, October 31, 2001

Potential Growth of Bioproducts



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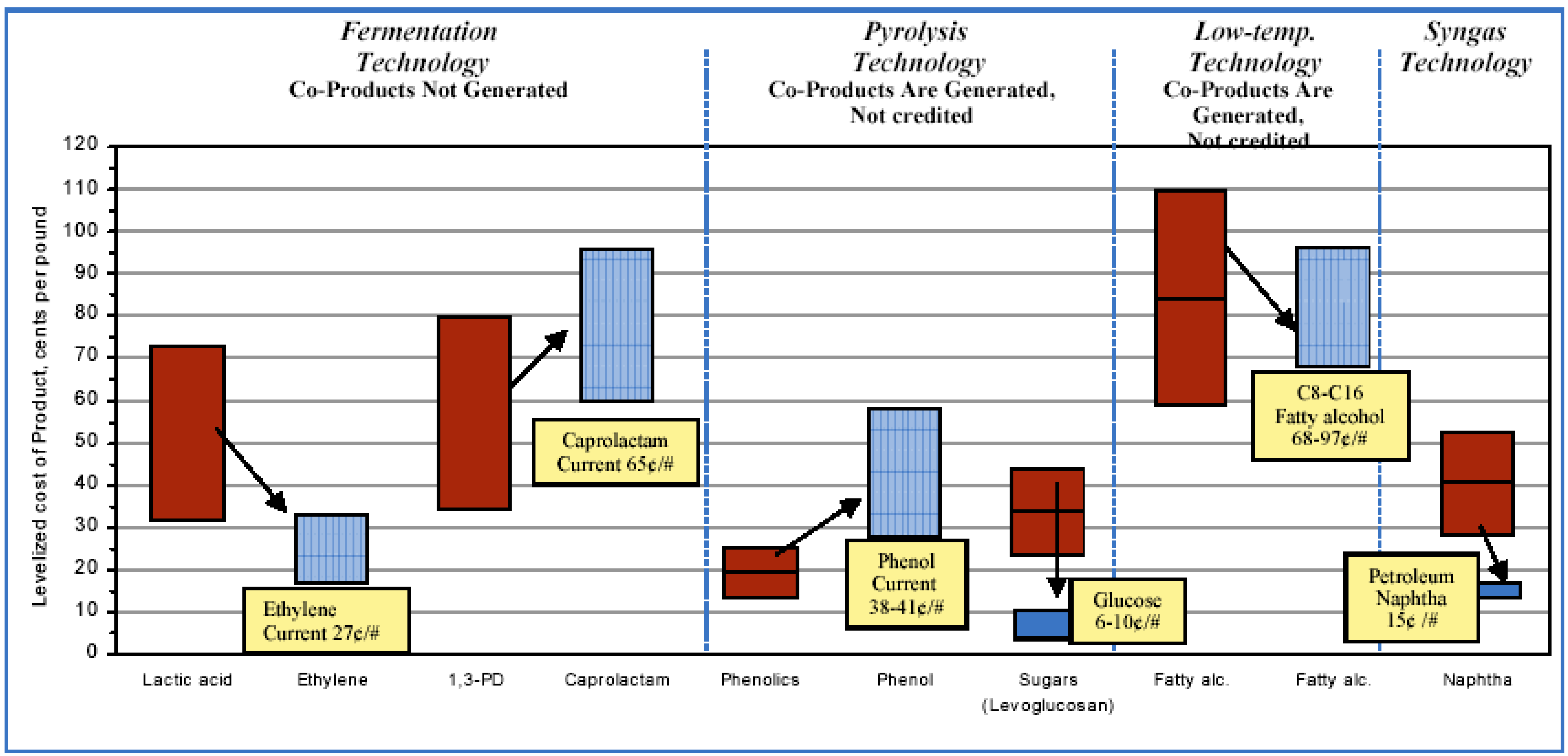
Cost of Production Examples



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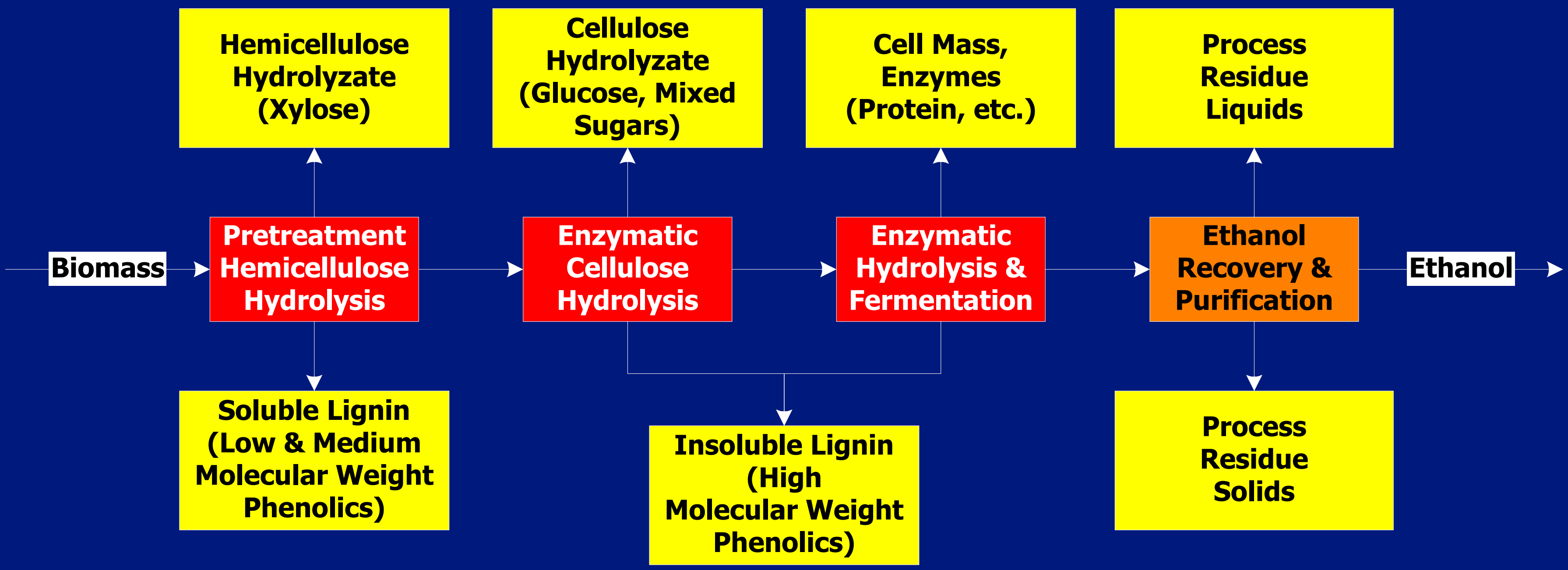
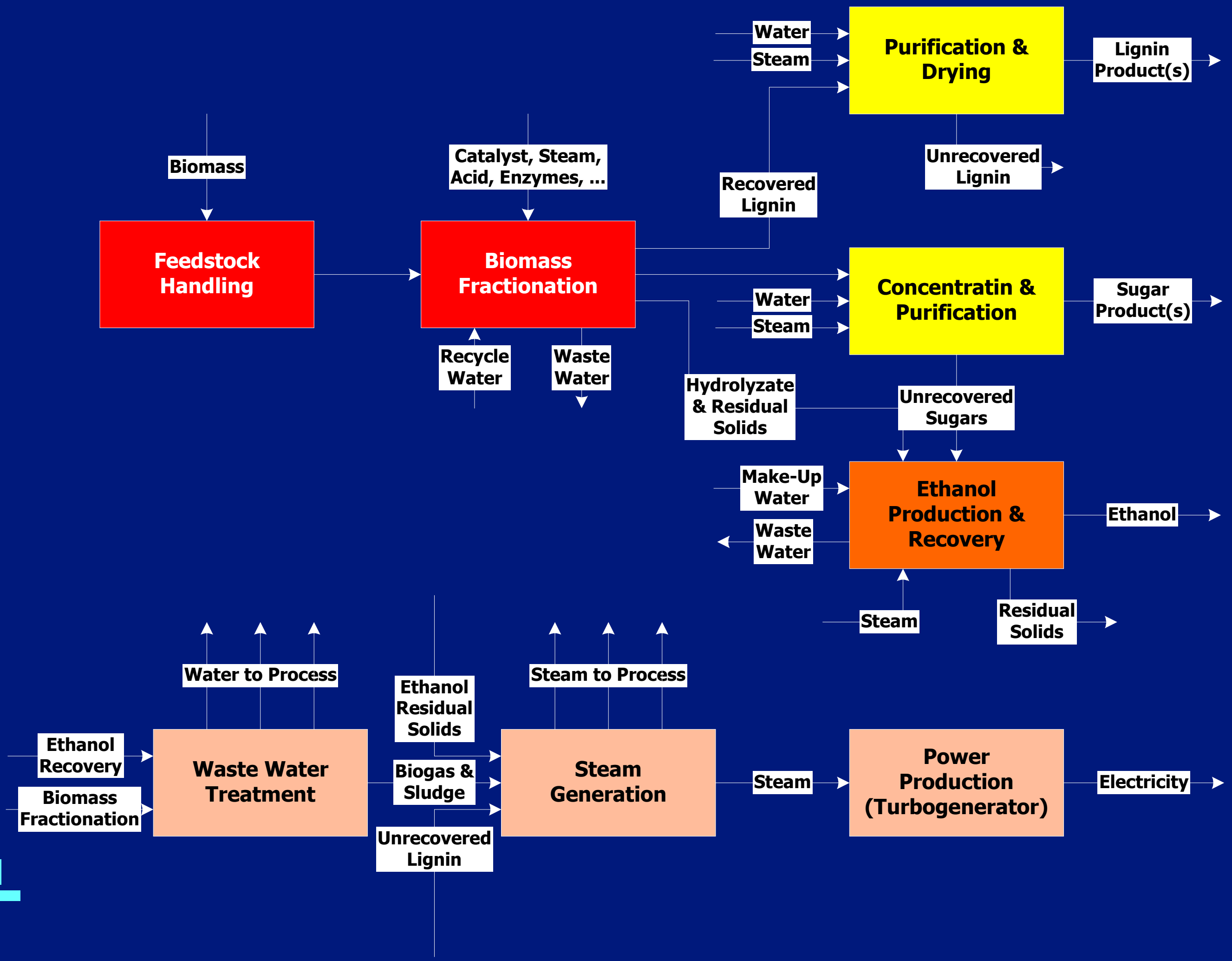
Potential Biorefinery Co-Products



Potential Sugar & Lignin Platform Biorefinery



U.S. DOE National Biofuels Program Subcontracts

“Strategic” Biorefinery Modeling

- Lynd, Wyman, et. al., Dartmouth College
- Outline potential directions for biorefineries
  - » Review existing refinery & biorefinery examples
    - – Examples: wet & dry corn mills, petroleum refineries
  - » Outline potential biorefinery scenarios
- Delivery expected by Fall 2002

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U.S. DOE National Biofuels Program Subcontracts

"Optimization" Biorefinery Modeling

- J.J. Marano, University of Pittsburgh
- Computer tool to pick between different processing & product options
  - » Microsoft® Excel-based
  - » Analogous to linear & nonlinear programming tools used in the petroleum industry
- Delivery expected by Fall 2002

Sugar Platform DDRD

Director's Discretionary Research and Development funding

- NREL's DDRD Program aligned with DOE's Office of Energy Efficiency & Renewable Energy (EE) policy

Objective

- Focuses on identifying opportunities to use lignocellulosic biomass to expand the existing industrial sugars platform to include xylose

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Sugar Platform DDRD

Expected Outcome

- Strengthen NREL's core expertise & capabilities
  - » Sugar separations (concentration & purification)
  - » Mixed sugar & hydrolyzate fermentations
    - – Aerobic & anaerobic
    - – Bacterial & fungal
  - » Biorefinery process modeling & simulation

A successful outcome will advance the national goal of tripling production of bio-based products by 2010

Acknowledgments

Office of Fuels Development of the

U.S. Department of Energy

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Director's Discretionary Research and Development Program of the National Renewable Energy Laboratory